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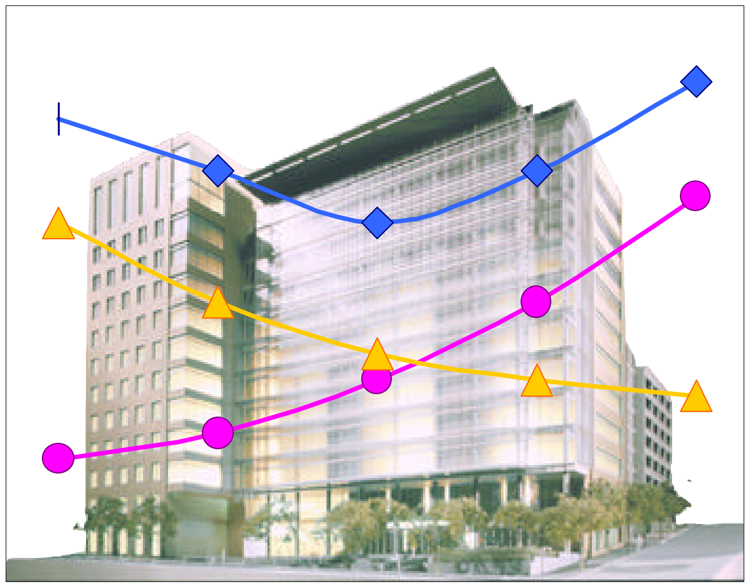
Green Building Strategies

A Primer on Life Cycle Assessment for Sustainable Building Projects



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What Is Life Cycle Assessment?

Life Cycle Assessment (LCA) is an informed decision-making process that is applied to building components, design strategies, and other measures associated with building alternatives. It is a holistic approach to identify economic, environmental, design, performance, cultural, and legal consequences of a product or facility through its entire life cycle. LCA information is beneficial because it compares initial capital costs to ownership and maintenance costs over a specified lifetime. Life cycle assessment is also referred to as life cycle analysis.

Why Use Life Cycle Assessment?

Building owners typically consider the initial purchase price or construction costs of their investment but do not consider operation and maintenance costs such as cleaning, repair, and replacement over the lifetime of the building. However, these on-going costs are typically equal to or greater than the initial capital costs. Therefore, it is valuable to consider future costs as well as present costs.

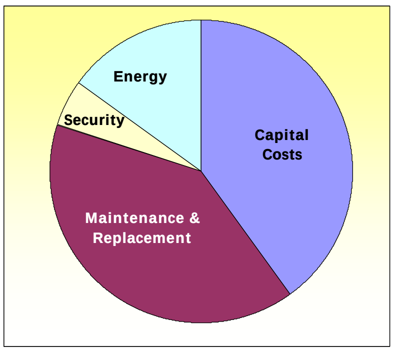

Figure 1 Total building costs to owner

Figure 1 illustrates a cost breakdown for a typical building. The graph shows that capital costs account for less than half of the total building costs to the owner. The remaining costs consist of maintenance and replacement, energy, and security. These are on-going costs that are not included in the initial capital expenditure.

How Are Life Cycle Assessments Used?

LCAs are used to make an informed choice between competing options based on several criteria including economic, environmental, design, performance, cultural, and legal requirements. In addition, LCAs can be used for budgeting future expenditures and to support decisions made for the future. Finally, they can be used as a tool to ensure that a facility is being utilized effectively and to maximize the value of the expenditure.

LCAs can be applied to a wide variety of decisions including accept or reject options, design and sizing, location, replacement, lease or buy options, system interdependence, budget allocation, and priority or ranking methodologies. LCA is traditionally used to assess direct costs of a building such as energy and water costs, building renewal and replacement, and operation & maintenance (O&M) costs. LCAs can also be applied to indirect costs such as staff salaries, staff productivity, lost construction time, fire insurance, lost revenue due to downtime, and other costs that are not directly related to the cost of the building. While these indirect costs are often more difficult to estimate than direct costs, they are significant and should be considered in the decision-making process.

When analyzing buildings, LCAs are useful for the comparison of long-term costs such as cleaning, maintenance, and replacement with short-term costs that include the initial capital cost of the building itself. For example, an LCA might be helpful in determining whether a building with a higher initial capital cost would save money in the future because of improved durability or decreased maintenance costs. Comparison of long-term costs to short-term costs is an effective method for the inclusion of all relevant costs in the decision-making process.

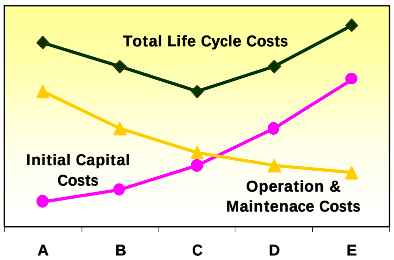

Figure 2 Using LCA to compare five alternatives based on cost

Figure 2 illustrates how different building design alternatives can be compared using LCA. Five alternatives (A, B, C, D, and E) are shown on the X-axis with data points for O&M costs and initial capital costs. If LCA is not used, the only consideration for deciding among the alternatives is the initial capital cost. In that case, the alternative with the lowest initial capital cost, Alternative A, would be preferred. However, when LCA is applied to the decision-making process, the operating and maintenance costs are also considered. By adding the initial capital costs to the operating and maintenance costs, the total life cycle cost is determined. Using this strategy, the most economical choice is Alternative C because it has the lowest total life cycle cost (i.e. the lowest combined costs for capital and O&M).

What Are The Steps Involved In Life Cycle Assessment?

There are six steps involved in applying LCAs to the decision-making process. These steps are summarized as follows:

Step 1 — ***Define objectives***: In this stage, the focus of the LCA is defined. It is important to identify the individuals affected by the proposed alternatives including building owners, occupants, and design team members. It is also helpful to develop specific criteria to measure the effectiveness of each alternative.

Step 2 — ***Identify alternatives***: The types of alternatives considered depend on the creativity of the design and management teams. The alternatives should represent a wide range of solutions to the identified problem. It is often helpful to use an interdisciplinary team during this stage to draw from a wide range of backgrounds, perspectives, and past experiences.

Step 3 — ***Define assumptions***: Assumptions must be made with regard to the future. These assumptions should include the period of time being analyzed and the discount or interest rate.

Step 4 — ***Assess costs and benefits:*** There are typically two types of costs that occur, non-recurring and recurring. Non-recurring costs appear as a lump sum cost in the present or at a fixed point in the future. An example of a non-recurring cost is the capital expenditure for a new high-efficiency chiller unit. Recurring costs are paid out periodically over the lifetime of the facility. An example of a recurring cost is a capital cost that is spread out over periodic payments. Repair costs that occur on a regular basis are also considered to be recurring costs. Benefits are accounted for as negative costs. For example, energy savings from a high-efficiency chiller are considered as negative costs.

Step 5 — ***Calculate net present value***: To evaluate the alternatives, all of the costs and benefits have to be normalized to the same point in time. In other words, capital costs and maintenance costs need to be comparable. To accomplish this, the costs and benefits are converted to either present value or annual value. Once the costs and benefits have been normalized, a comparison is performed by summing the costs and benefits to arrive at a total cost. The general formula is as follows:

+	Initial Cost
+	Energy
+	Maintenance/Repair
+	Replacement/Modernization
-	Salvage/Resale
=	**TOTAL COST**

Step 6 ***Select one alternative***: The selected alternative is usually the one with the lowest lifetime costs. However, other criteria might also influence the selection process. These other criteria might include risk minimization, ease of implementation, institutional policy, and other intangibles.

What Are The Disadvantages And Limitations Of LCA?

While LCA is a powerful tool for making decisions, there are several disadvantages and limitations that are important to recognize.

Data Limitations: It is not always possible to locate reliable data on future performance of buildings or materials, maintenance frequency, and O&M costs because these costs vary over time. In some instances, it is only possible to make an educated guess at these figures. For instance, the lifetime of a roof may range from ten to twenty years, depending on the maintenance applied, weathering over the lifetime of the roof, and other variables. The LCA for the roof would require a specific number for the roof lifetime but it may only be possible to provide a best guess estimate. It is not always clear how these assumptions will change over the lifetime of the building. The assumptions may become erroneous or invalid in the future and nullify the LCA results. Thus, it is important to document any assumptions made and modify them when appropriate.

Manufacturer Reservations: Building product manufacturers are sometimes wary of providing lifetime information on their products because of conditions beyond their control (i.e., environmental conditions and maintenance procedures). It might be possible to find data on other buildings but even slight differences between buildings can affect the lifetime significantly.

Time Constraints: Building projects are often constrained for time during the design process. Budget constraints may also discourage the in-depth economic analysis of different building options. An LCA may be too complex or time-consuming to be beneficial, especially for smaller projects that have a small design team or small budget. LCAs are usually an involved process and may not be cost-effective for all projects.

Institutional Constraints: Institutional accounting policies might discourage or inhibit the application of LCA. For instance, a company s purchasing protocol might not allow expenditure for a higher quality alternative. Instead, the purchasing protocol might force the purchase of the alternative with lowest cost and thereby override the results of the LCA process.

A Life Cycle Assessment Example

To illustrate the application of LCAs, a lighting alternative is considered that includes initial capital cost and energy savings over the lifetime of the lighting system. When applying LCA to buildings, it is common to assume a standard economic baseline and then examine the effects of different alternatives over and above this baseline.

This example considers the application of a daylighting scheme in a typical office building. The baseline lighting scheme is a direct general lighting scheme that is common in office environments. The daylighting alternative utilizes natural light through a combination of shading devices, window glazing, direct/indirect dimmable fluorescent fixtures, and photo-sensors. The primary goal of the daylighting scheme is to improve the workspace environment and increase worker productivity. A secondary goal of daylighting is utilizing natural light to reduce the amount of energy used in the building.

The data used in the LCA is organized into four sections: *office information*, *first costs*, *energy savings*, and *indirect savings*. Office information consists of general building information and includes assumptions regarding the effect of the daylighting scheme, such as the percent gain in productivity as a result of adopting the daylighting scheme. The first costs include material and installation costs as well as design costs. Energy savings are calculated using the price of electricity and the savings associated with the alternative scheme. **Table 1** lists components in each of the four sections.

Office Information	
Number of floors	3
Daylighting area (sf)	5,100
Electricity costs (per kWh)	$0.07
First Costs	
Photosensors	$3,060
Window glazing	$117,875
Dimming fixtures	$12,240
Total first costs	**$133,175**
Energy Savings	
Lighting savings (per year)	$1,515
Cooling savings (per year)	$606
Total energy savings (per year)	**$2,121**
Indirect Savings	
Estimated productivity gain from daylighting	1%
Annual personnel cost	$4,200,000
Productivity gain (per year)	**$42,000**

Table 1 LCA cost estimates

To illustrate the concept of net present value, the example building is used to forecast the direct and indirect potential savings for the project stretched over a period of fifteen years. The standard office building has three floors of an area of 10,000 square feet each. Of that area, approximately 5,100 square feet of the building perimeter is daylit.

The first costs include those devices that would be considered additional expenses to the standard building, such as photo sensors, improved window glazing and dimming features in the daylit zone. The resultant savings from these combined approaches fall into two categories. The first is the direct savings and include the energy savings of daylighting and reduced need for cooling. The indirect savings are estimated at a conservative 1% productivity gain for those employees located at the perimeter daylit area.

Upon comparison to the first costs, it is estimated that a simple payback period of only three years is needed to recoup the additional costs of the initial investment. The amount saved after that three-year period reflects a substantial return on investment.

First Costs	$133,175
Annual Energy Savings	$2,121
Annual Indirect Savings	$42,000
Simple Payback (in years)	3.02

Table 2 Simple payback calculation

Once all of the costs and benefits have been totaled, it is possible to calculate a simple payback for the alternative system. The payback represents the number of years required to recoup the additional capital expenditure through annual savings. Simple payback is equal to the first costs divided by the sum of the savings (see **Table 2**). In other words, it will take 3.02 years to recover the additional cost of adding daylighting. Recovery of the cost comes from energy savings and increased worker productivity.

In **Table 3** a cash flow diagram is used to compared the first costs with the net present value of the annual costs and savings for a fifteen-year period. Besides the first costs for the actual equipment, routine maintenance at the midpoint in the fifteen-year cycle is estimated at 5% of the first costs. Replacement of fixtures in the daylit area is estimated to include eleven fixtures within a five year period.

These annual estimated costs are then brought back to present day with a cumulative discount rate of 5% per year. Here in the first column it is easy to see the long-reaching benefits of the suggested energy saving features. The net present value of the potential savings far outweighs the initial first costs. The cumulative gains for both the indirect and direct costs can also be plotted in an investment growth diagram shown in **Table 4** where the indirect costs of a potential increase in productivity dwarf the actual energy savings.

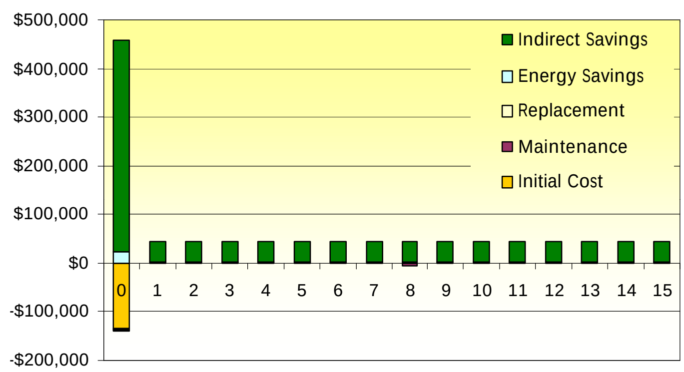

Table 3 Net present value of first and annual costs

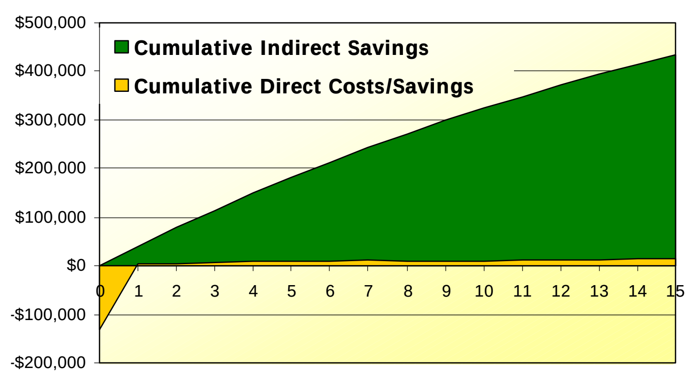

Table 4 Comparison of indirect and direct costs and savings

Life Cycle Assessment Definitions

Life cycle assessment — A holistic appoach to identify economic, environmental, design, performance, cultural, and legal consequences of a product or facility through its entire life cycle. Life cycle assessment is also referred to as life cycle analysis.

Life cycle — The period of time considered in the LCA, spanning the time from acquisition of raw materials to final decommissioning or disposal. For a building, the life cycle may be fifty years or greater. Larger infrastructure items such as heating and ventilating systems may have a life cycle of 20-30 years while building materials such as carpeting may have a ten year life cycle.

Life cycle costing — A method of economic evaluation to decide between building alternatives by comparing significant costs of ownership over a given time period. These costs include capital costs, operating costs, maintenance costs, and disposal costs. All costs must be in equivalent dollars in order for comparisons to be valid. This is typically achieved by converting all costs to a present value. It is based on the premise that buildings provide service over a period of time. Both future costs and present costs are important for minimizing total facility costs. It is also typically assumed that tradeoffs exist between initial capital costs and long-term costs.

Present value — Also called the present worth, this is the value of a cost or benefit discounted to the present time.

Net present value — Distinct from the present value the net present value (NPV) is the net value of all totaled costs and savings discounted to the present time.

Annual value — A uniform annual amount equal to a cost or benefit over the life cycle period.

Time value of money — The value of money due to changes in purchasing power over time (e.g., interest rates, inflation and deflation) and due to earning potential of alternative investments over time.

Discount rate — The rate of interest that reflects the time value of money. The discount rate is used to convert costs and benefits occurring at different times to a base time.

Payback method — This is a technique to determine the period of time required to recover the investment cost of a capital item through the item s cost-savings benefits over time. Simple payback is equal to the initial capital cost divided by the annual savings. Thus, an alternative with a higher annual savings will result in a faster simple payback period for an equal initial capital cost.

Life Cycle Assessment Resources

There are countless sources for information on application of LCA. Below is a select list of general books, technical references, information on the web, and LCA software resources.

General Books

Building Economics for Architects, T. Mann, Van Nostrand Reinhold (1992).

Building Economics: Theory and Practice, Ruegg and Marshall, Van Nostrand Reinhold (1990).

Design and the Economics of Building, R. Morton and D. Jaggar, E & FN Spon (1995).

The Economics of Building, R. Johnson, John Wiley & Sons, Inc. (1990).

Environmental Life Cycle Analysis, D. Claimbrone , 1997, CRC Press.

Life Cycle Costing, R. Flanagan, et al., 1989, Oxford.

Technical References

ASTM Standards on Building Economics, ASTM Subcommittee E06.81 on Building Economics, The American Society for Testing and Materials, (1990).

Mechanical and Electrical Equipment for Buildings, 8th Edition, B. Stein and J Reynolds, John Wiley & Sons, Inc. (1992).

Information on the Web

Canadian Newsletter on Product Environmental Life Cycle Management (www.ec.gc.ca/ecocycle/): A newsletter on policy and technical issues related to environmental LCA, including publications and software.

National Key Centre For Design at RMIT (daedalus.edc.rmit.edu.au/outcomes/papers/LCA-CR.html): A Paper from the Australian National Conference on LCA with extensive discussion of LCA and the design process.

Oak Ridge National Laboratory, Life Sciences Division, Assessment Technology Section (ats.ornl.gov): An online resource center for LCA including a list of LCA consulting companies.

Trent University Faculty Member Page (www.trentu.ca/faculty/lca): A webpage with information on LCA with hyperlinks to other LCA resources.

LCA Software

ATHENA: Sustainable Materials Institute (www.athenasmi.ca): A software program intended for building professionals in the U.S. and Canada.

Elite Software (www.elitesoft.com): A software program for LCA including several other tools for assessing building systems, including electrical, plumbing, HVAC and fire systems.

Ecobilan, Consulting and Software (www.ecobalance.com): A software program for LCA with a focus on assessment of environmental impacts.